AFRL-RW-EG-TM-2011-048

High Pressure Particulate Physics Facility

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March 2011

Final Report

**AIR FORCE RESEARCH LABORATORY
MUNITIONS DIRECTORATE**

■ **Air Force Materiel Command**   ■ **United States Air Force**   ■ **Eglin Air Force Base, FL 32542**

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1. REPORT DATE 26-03-2011	2. REPORT TYPE Final	3. DATES COVERED *(From - To)* Sept 2009–March 2011

4. TITLE AND SUBTITLE

High Pressure Particulate Physics Facility

5a. CONTRACT NUMBER

5b. GRANT NUMBER

5c. PROGRAM ELEMENT NUMBER
62602F

6. AUTHOR(S)

W.R. Maines, W.L. Cooper, L.C. Chhabildas,

5d. PROJECT NUMBER
2502

5e. TASK NUMBER
13

5f. WORK UNIT NUMBER
04

7. PERFORMING ORGANIZATION NAME(S) AND ADDRESS(ES)

Air Force Research Laboratory, Munitions Directorate
AFRL/RWMW
101 West Eglin Boulevard
Eglin AFB, FL 35542-6810

8. PERFORMING ORGANIZATION REPORT NUMBER

AFRL-RW-EG-TM-2011-048

Air Force Research Laboratory, Munitions Directorate
AFRL/RWMW
101 West Eglin Boulevard
Eglin AFB, FL 32542-6810

10. SPONSOR/MONITOR'S ACRONYM(S)
AFRL-RW-EG

11. SPONSOR/MONITOR'S REPORT NUMBER(S)
Same as Block 8

12. DISTRIBUTION / AVAILABILITY STATEMENT

DISTRIBUTION A. Approved for public release, distribution unlimited. 96th ABW/PA Approval and Clearance # 96ABW-2011-0155, dated 29 March 2011.

13. SUPPLEMENTARY NOTES

14. ABSTRACT

This report documents the initial development of the High Pressure Particulate Physics (HP3) facility. The facility is anticipated to allow precision impact of two flat plates at a very high degree of precision with minimal misalignment when completed. A 60 mm smooth bore powder gun will be used to achieve this capability. Impacts will occur under high vacuum conditions. The gun will fire projectiles that carry a faced material at the nose and will impact a stationary target at the muzzle end. High precision time-resolved diagnostics shall record dynamic impact responses in materials of interest under high strain rates. Our goal is to perform well controlled and repeatable experiments to provide accurate equation of state data and constitutive properties of materials of interest to the Air Force to develop robust computational models, which are physically based. This new thrust at AFRL/RW is addressing a recommendation made by the Scientific Advisory Board in 2007.

15. SUBJECT TERMS
60mm smooth bore gun, high velocity impact, equation of state, high strain rate experiments

16. SECURITY CLASSIFICATION OF:			17. LIMITATION OF ABSTRACT	18. NUMBER OF PAGES	19a. NAME OF RESPONSIBLE PERSON Warren R. Maines
a. REPORT UNCLASSIFIED	**b. ABSTRACT** UNCLASSIFIED	**c. THIS PAGE** UNCLASSIFIED	UL	10	19b. TELEPHONE NUMBER *(include area code)* 882-7995

PREFACE

This report was prepared at the Damage Mechanisms Branch (AFRL/RWMW) of the Air Force Research Laboratory, Ordnance Division, Munitions Directorate, Eglin Air Force Base Florida, with contributions from Adam White, Richard Davis, Richard Harris, Daniel Vu, Bill Peaden, Robert Hammack, and Joseph Boylan.

ACKNOWLEDGEMENTS

The High Pressure Particulate Physics Facility construction would not be possible without the tremendous effort of the 96th Support Squadron, 46th Systems Integration Squadron and AFRL/RWMW including U.S. Government and Indyne, Inc. personnel. We also wish to thank Sandia National Laboratory at the Shock Thermodynamics and Research Facility for their continuing expertise and guidance building this facility. While the vast number of contributors are too enumerable to list, we do wish to thank the following people for their outstanding contributions to the facility's successful construction:

Mr. Randal Miller, Mrs. Manivahn Mundi, and Mrs. Brisa executed equipment and facilities construction contracts (96th Support Squadron)

Mr. Gordon Doyle oversaw the facility construction (96th Civil Engineering Squadron)

Mr. Christopher Evans allocated resources and heavy equipment required to integrate working equipment (AFRL/RWMW)

Mr. Patrick Connolly oversaw the finances and acquisitions of supplies and equipment (TAMS/TEAS)

Mr. David Strange refurbished the previously existing 60mm gun (Physics Applications, Inc.)

Captain Andre McDonald managed the project time line (AFRL/RWMW)

Mr. Richard A. Davis, Mr. Adam White, Mr. John Licht, integrated all interfaces and supported electro-optical development.

Mr. Hugh Hood, Mr. Jim Rachels and Mr. Eric Buckthal designed and constructed control and diagnostics systems (46th Systems Integration Squadron)

TABLE OF CONTENTS

LIST OF FIGURES

SECTION I

BACKGROUND

The High Pressure Particulate Physics Facility (HP3 Facility) is being developed to investigate strategic materials to meet USAF needs. Examples of materials under investigation will include warhead metals (1), high density liner materials (2), air force explosives (3), reactive materials (4), structural energetics (5), and high strength concrete (6). To obtain accurate equation of state, one needs to measure the impact velocity, V, of the projectile plate to within 0.1%. The resulting shock velocity, U,s must be determined to within 1%. Using Rankine-Hugoniot (7), (8) relations namely,

$$P = \rho\, Us\, up \qquad\qquad 1)$$

$$\frac{V}{Vo} = 1 - up/Us \qquad\qquad 2)$$

where *up* is the particle velocity in the material, *P* is the stress and *V/Vo* is the resulting volume compression in the material. Hence, to measure stress and volume compression to a high degree of accuracy it becomes necessary to measure the shock velocity and the particle velocity very precisely. For symmetric impact experiments (9) where the projectile and the target materials are the same the particle velocity will be one half of the impact velocity. Precision gun (10) impacts allow a square pulse input to be introduced into the material. The design of the projectile nose plate can be used to tailor the input pulse. For example, the thickness of the projectile plate will determine the pulse width that is introduced in the material (11). The nose plate backed by a low-impedance or high-impedance material will introduce a release wave or re-shock wave in the material. Re-shock/release wave experiments are necessary tools/techniques to probe material properties in the shocked state. A series of layered materials will allow isentropic loading of the material mimicking ramp loading in the material.
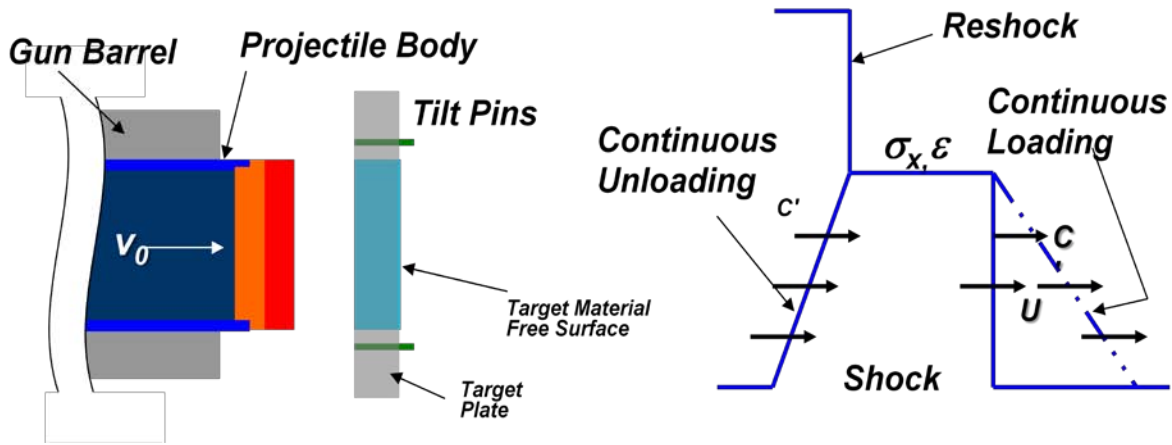
Figure 1. Examples of stress pulses that can be introduced in a material using smooth bore guns.

To complement well-controlled loading conditions, nanosecond time resolution diagnostics are required. Therefore, state of the art diagnostic tools such as Velocity Interferometer System for Any Reflector (VISAR) (12), or Photonic Doppler Velocimetry (PDV) (13), shall be the dominant tool used in these experiments. The responses captured from these diagnostics will be either at the free surface, or at an interface of a transparent window.

Once the particle velocity and shock velocity of the material is acquired, all other properties of the material can be determined including, strain/density, or volume compression and stress as described above. The locus of the material end states define the material's equation of state, also known as the shock Hugoniot.

There would be very little variation in the shock Hugoniot state if the material under investigation were homogeneous (14). However, many materials described above they are intrinsically heterogeneous in their make-up and it is anticipated that a heterogeneous response would be observed (15) (16). It is our intent to characterize this response when investigating non-homogeneous materials.

SECTION II

DESCRIPTION OF FACILITY

The HP3 Facility is located in Building 9633 at the Advanced Warhead Experimentation Facility (AWEF) at Range C-64C, Eglin Air Force Base, Florida. The building was modified to house the 60mm bore gun, a catch tank and related accessories that are necessary to operate the facility and conduct experiments. This includes vacuum systems, a hardened and armored control room, sample preparation room and a lapping room. A schematic of the system is shown in Figure 2.
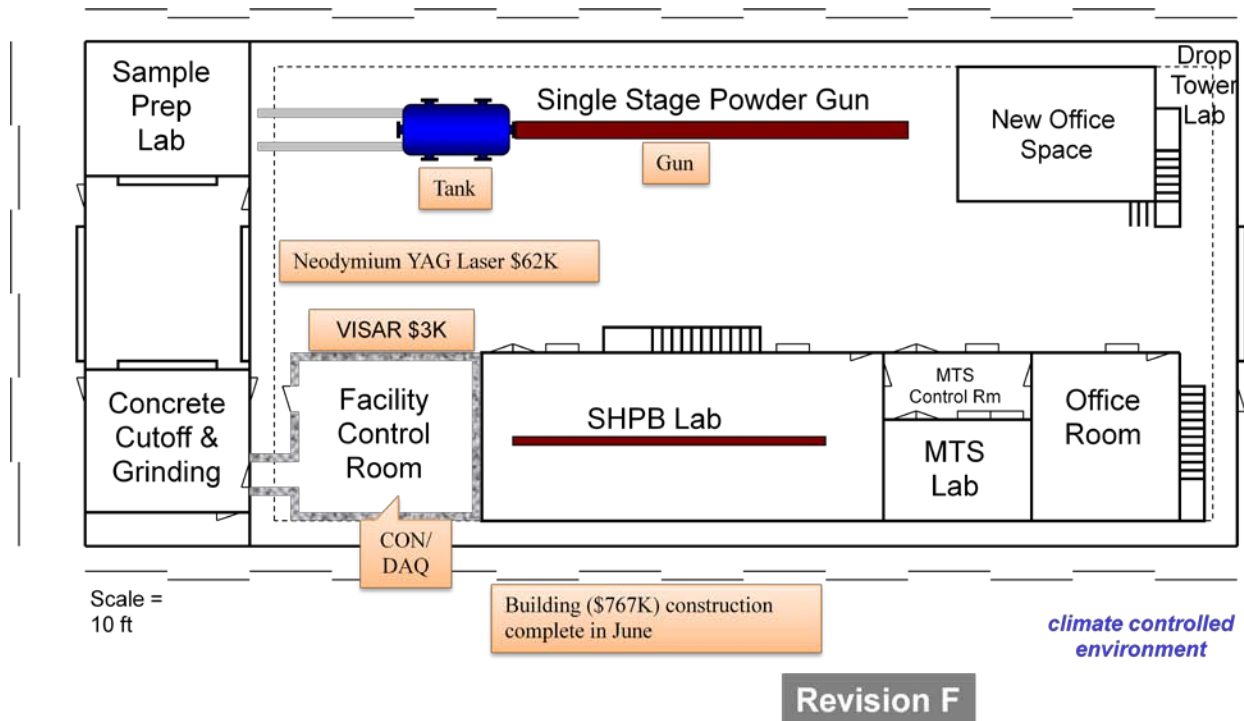

Figure 2 Floor plan of the HP3 Facility

The 60 mm ballistic launcher has an outside diameter of 8 inches, and runs 45 feet long from breech to barrel extension. It was reclaimed from a gun that was previously utilized at C-64 C. The gun's new breech is rated at 90 ksi maximum dynamic pressure. A gun barrel extension was permanently attached to the gun barrel and was made to prevent damage to the main barrel from fragments resulting from project/target interactions.

The projectile will be accelerated using M30 propellant powder which will be energized using a standard percussion initiation system. The entire system meaning the gun barrel and the catch tank will be evacuated prior to impact experiments. This is done to prevent pre-compression of the target sample that will be mounted at the muzzle end. Impact velocities over the range of 500 m/s to 2200m/s are anticipated. Figure 3 shows the layout of the integrated equipment.
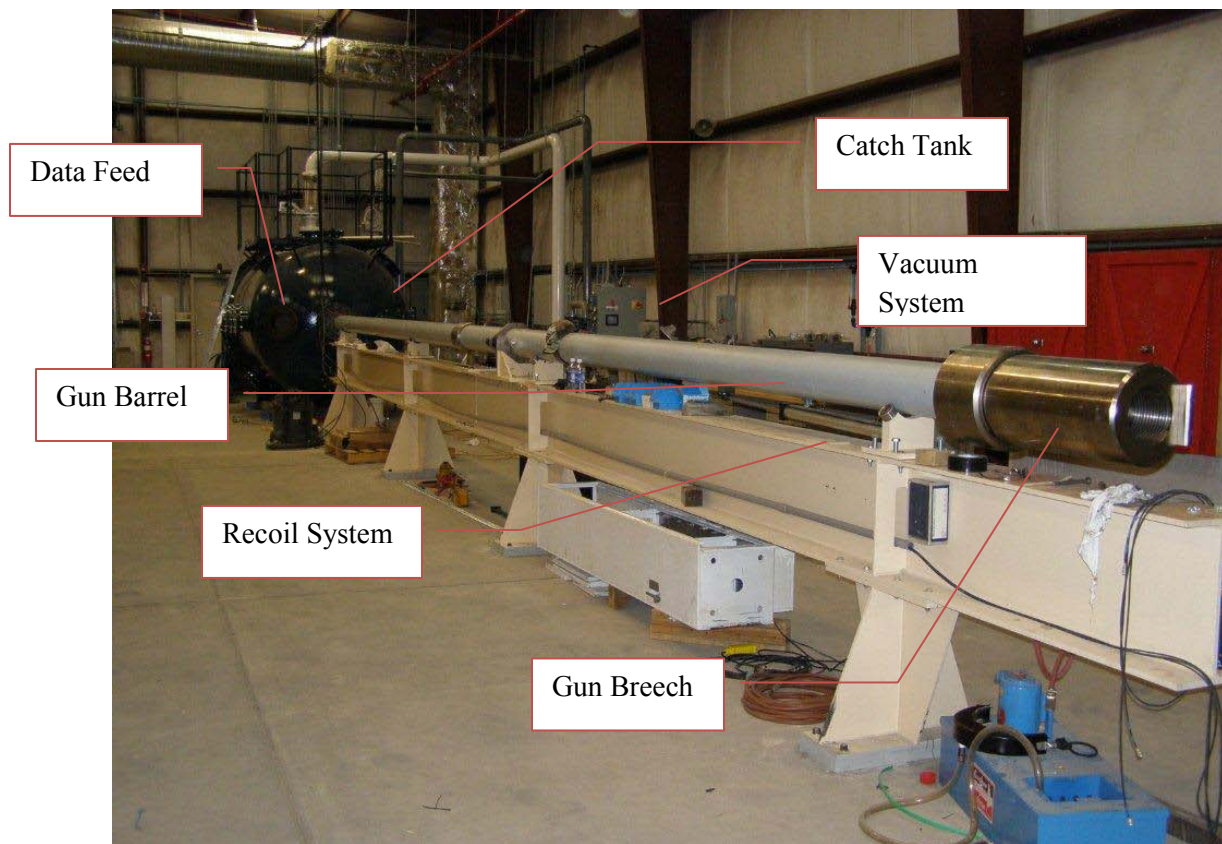

Figure 3 General equipment lay out of HP3 integrated system.

Figure 4 is an artist's rendering of a cross-sectional view of the catch tank. The gun barrel is inserted through the sliding seal, and diagnostics are connected via feed-through. The back of the catch tank features a series of steel plates connected to a large door, which is moved by air bearings.
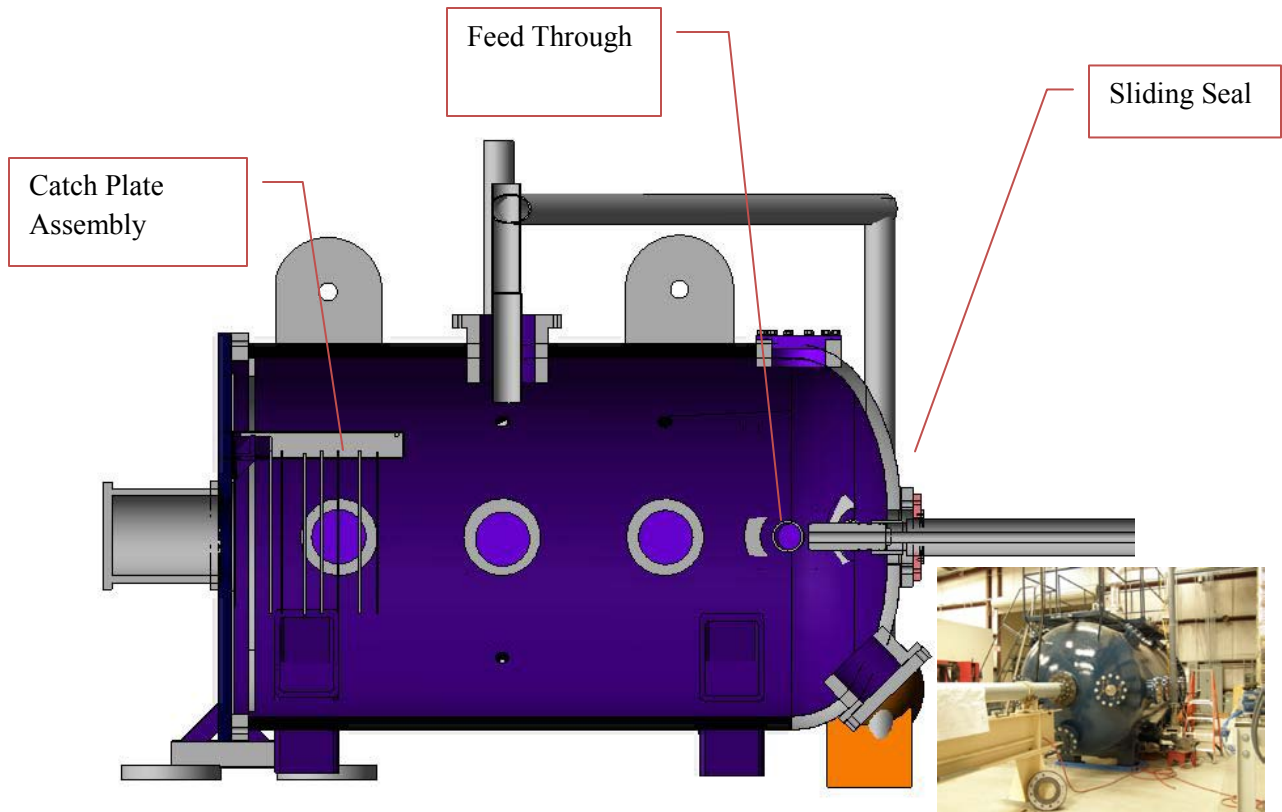
Figure 4 Artist's rendering of a cross section of the fully assembled catch tank. Lower right, photograph of catch tank.

The catch tank is where the projectile shall impact the target. It has a volume of 400 standard cubic feet, and is rated for 2000 psi. The sliding seal, which couples the gun to the catch tank, maintains the vacuum in the catch tank.

The projectile-target interaction zone is located 30 inches behind the barrel entrance into the catch tank and is collocated on the centerline of the catch tank. The debris from the projectile target interaction is stopped using a catch plate assembly located at the rear of the catch tank. The catch plate assembly consists of four ¼" thick steel plates and four ½" thick steel plates suspended by a rack system that is attached to the door of the catch tank. Figure 5 shows the rear view of the catch tank. Access is needed inside the catch tank to set up the experimental target.

The target mounting assembly is shown in Figure 6. It is designed to allow projectile target interaction to occur with minimal impact misalignment (17). Techniques have been developed to ensure that the target mount is precisely normal to the projectile trajectory (i.e. the barrel axis). Identified in Figure 6 are the mounting plate (green), the target alignment ring

(grey) and the target plate (silver). The entire assembly is mounted on a table. On the left of Figure 7 shows an artist rendering of a projectile impact, with the target assembly mounted on the table. On the right of Figure 7, the target mount and the alignment ring are installed at the muzzle end of the barrel. This assembly is crucial and is a significant part of the high precision requirements of the projectile target interaction since impact planarity of the order of a few milli-radians are anticipated.

Figure 5 Rear View of Catch Tank

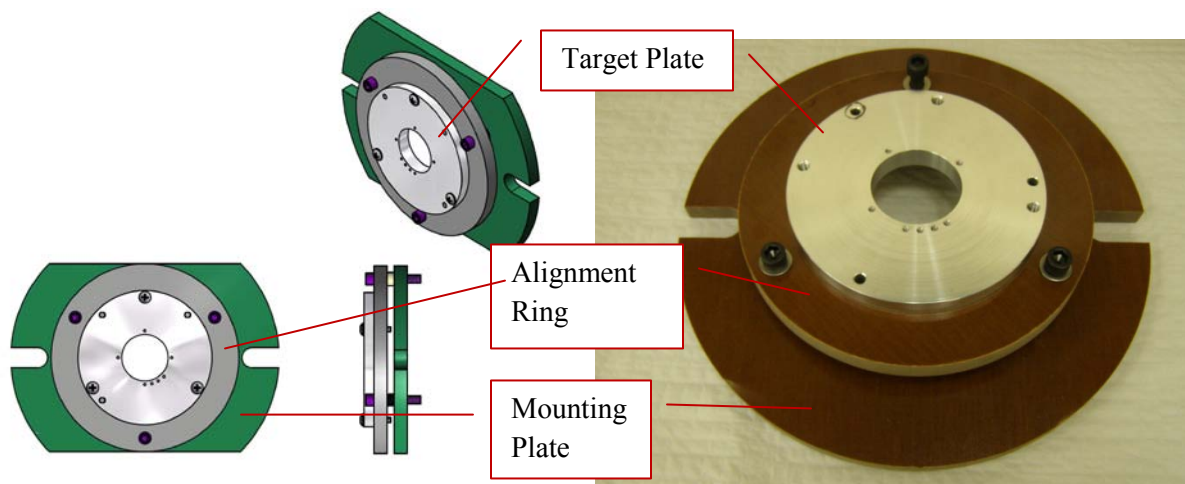Target Plate

Alignment Ring

Mounting Plate

Figure 6 Artists rendering of target mounting plate (green), alignment ring (grey), target plate (silver). Fully assembled target, which consists of the mounting plate, alignment ring and target plate without the materials sample.
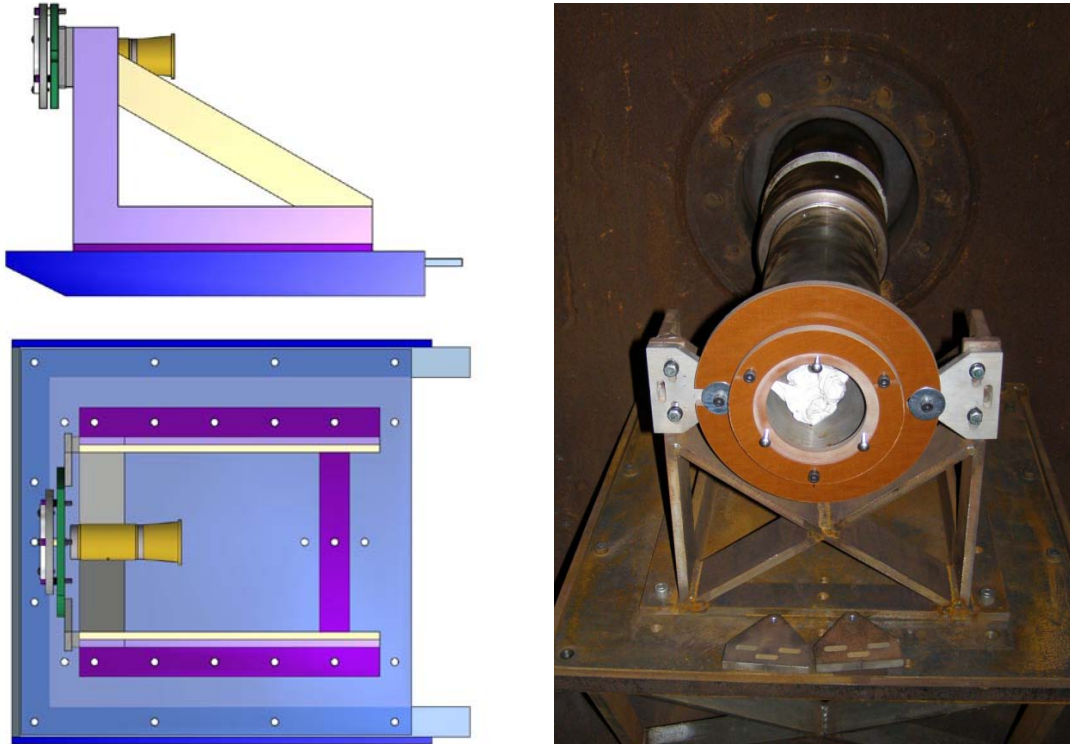
Figure 7 rendering of projectile target interaction (impact) is shown. On right, the target mount installed at gun barrel muzzle.

In Figure 8, a standard projectile is shown. The standard projectile consists of an obturator (boot), the projectile body and two metallic plates, one at either end. The front plate metallic plate holds a standard impacter material. Standard impacters will consist of either ploymethylmethacrlate (PMMA), fused silica, sapphire, aluminum, copper, steel or tantalum. The low density materials will generate a lower pressure/stress upon impact, while the high density materials will introduce higher stresses at the same impact velocity.
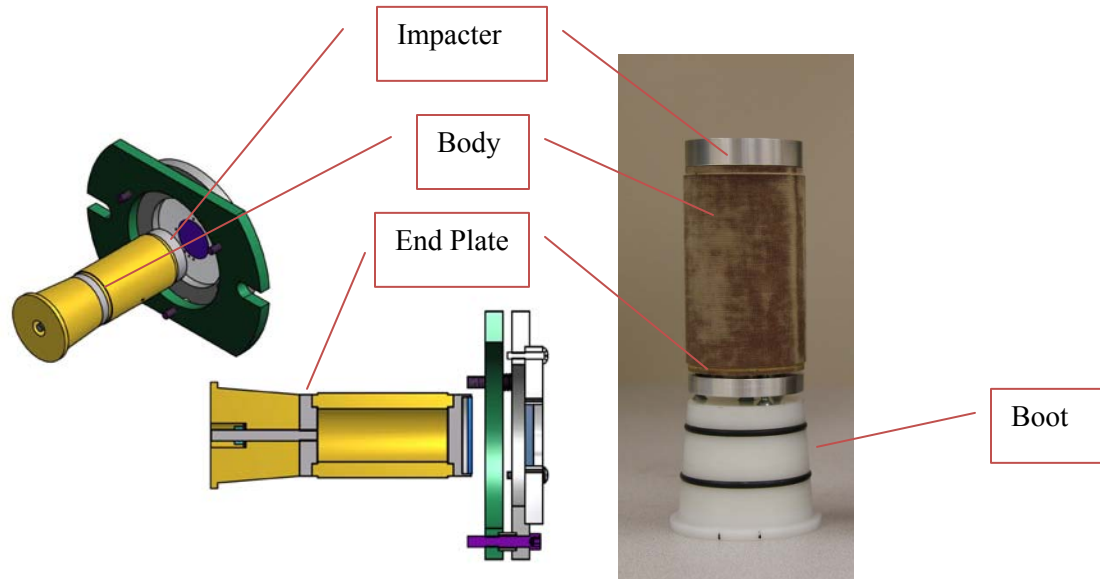
Figure 8 The projectile design consists of a) the polyethylene boot, b) end metallic plate, c) projectile body, d) front metallic plate, and e) impacter facing/assembly that is of interest in the experiment.

As indicated in the above pictures, a projectile will be traversing the length of the gun barrel and will impact a stationary target at the end of the muzzle. We have also designed the projectile body that will carry an impacter facing on its nose. The main requirements of the projectile body is that it can withstand the acceleration loads of the order of 10^4 and 10^5 gee loadings as it is accelerated through the launch tube. It also has to prevent the propellant gaseous products from blowing by (10) ahead of the projectile as it is being accelerated. To achieve these objectives we have used a proven design used at other facilities (18). It consists of three main parts: 1) a high density polyethylene boot that can withstand these loads and will dynamically deform to conform to the dimensions of the barrel to prevent gas blow-by, 2) a projectile body constructed of linen-phenolic composite, 3) metal end plates. The metal plate in the back allows us to attach the polyethylene boot while the impacter assembly is attached or glued on to the front end plate.

The Data Acquisition System (DAS) is based on the state of the art National Instruments PXI system. The architecture provides the industry's highest bandwidth and lowest latency and highest resolution up to 26.5 GHz. The PXI architecture can address automated experimental needs in a very small frame. The chassis of the system is small enough to fit on the desktop, and has enough flexibility,

such that oscilloscope temporal resolution can be switched out simply by changing oscilloscope cards. The system provides a software interface, a switch block that minimizes wiring and simplifies connectivity, while allowing for intelligent integration with other software for data analysis. Table 1 describes a sample list of common expected diagnostics that will be used. It is armed with 100MHz and 2GHz oscilloscope cards with 20 available channels.

Table 1 Data acquisition capability. Breech pressure is monitored by the control circuit.

Signal Source	# of Source Channels	Minimum Sample Rate	Multiplexed (Y/N)	# of Data Channels
Velocity Pins	3	100MHz	Y	1
Tilt Pins	4	100 MHz	Y	1
Breech Pressure	1	100 KHz	N	2
VISAR	12	2 GHz	N	12
Configurable	4	2 GHz	N	4

The data acquisition system acquires all electrical signals from the catch tank. High resolution information, such as shock wave and particle velocities are obtained via fiber optic. Lower resolution, such as impact velocity and planarity are obtained by copper wire. In the future x-ray cinematography, line VISAR and time indexed spectroscopy are planned.

SECTION III

SUMMARY

We are developing a facility called the HP3, in which investigations into dynamic material responses to impact velocities around 500m/s to 220m/s shall occur. These are commensurate with ordnance velocities of interest not only to our Air Force needs but also to the entire DoD. This will be a unique facility to the Air Force that allows well-controlled experiments to be conducted at extremely high precision. Determining an accurate equation of state of materials requires sudden high stress loading in well controlled impact conditions. We have successfully refurbished an existing powder gun that shall meet the velocity requirements. Further, we have designed the necessary accessories such as the catch tank, vacuum system, firing systems, projectiles, and target mounting systems that shall accomplish the precise alignment. The gun system shall be complemented by state of the art diagnostics such as VISAR or PDV velocity interferometers, which provide the necessary temporal resolution on the order of nanoseconds. The data acquisition system is compatible with the high band width requirements of shock physics to detect elastic and plastic deformation as materials undergo high velocity impact.

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